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Co-managing carbon emissions and air quality: pros and cons of intersectoral local scale initiatives

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Abstract

Emergence of 'co-management' i.e. linked actions for managing environmental and public health issues, particularly air quality, alongside pursuing climate change mitigation and adaptation agenda has gained grounds in times of austerity. This paper looks at some of the pros and cons of implementing this approach at local scales. Three intersectoral case studies are presented, each depicting unique outlooks of sustainability practices currently being promoted. The Reading Borough Council Air Quality and Climate Change consultation process (Case Study I) highlights how co-management can meet the need for political win-wins, as well as practical ones, through integrated policies to consolidate a range of council activities. The All London Green Grid development (Case Study II) illustrates the role of Green Infrastructure planning initiative towards local air quality management while enhancing green space cover for aesthetic and carbon sequestration potentials. The Decentralised Energy from Renewable Fuels initiative (Case Study III) provides evidence base for policies towards more holisitc management of such diffused installations.

The case studies offer useful insights on the merits and the trade-offs of implementing local scale co-management practices, both for reducing carbon intensity and for improving air quality using a more integrated framework than what is currently under offer. At the same time the paper recognises that delivery of such ambitious, cross-cutting agenda may be impeded, primarily owing to limited expertise in assessing the synergies and the expected outcomes from cross-fertility between these two arenas. It calls for a step-change through more cohesive, cross-disciplinary policy frameworks, going beyond the local administrative spheres to maximise the co-management potentials while mitigating the wider environmental impacts.

Keywords: carbon emissions; co-management; air quality; green infrastructure; local authorities

1. Introduction

Globally there is growing emphasis on concerted, inter-sectoral actions at local scales through generic sub-national and national policies for maximising the co-benefits of climate change adaptation strategies to human health from improved air, water and food quality (Haines et al., 2007; Salon et al., 2010; Quevauviller, 2011; Larsen et al., 2012; Takeshita, 2012). The majority of 'conventional' air pollution as well as CO_2 emissions at a local level originate from anthropogenic sources; measures to reduce one problem are likely to have some impact on the other (Hayes et al., 2007). National and federal governments have been increasingly empowering local authorities (LAs) to take action through localised management solutions given their wide range of responsibilities and greater understanding of underlying activities (Salon et al., 2010; DECC, 2012; Naiker et al., 2012). Owing to the lack of a formal policy 'home' for climate change within LAs in the UK, there has been a particularly strong set of arguments for integrating climate change strategies into aspects of well-established local air quality management (LAQM) remits. These initiatives have been broadly referred to as 'co-management' (Baldwin et al., 2009).

There have been significant calls for integrated policies, linking disparate air pollution and climate change management initiatives (van Amstel, 2009; Defra, 2011; EPUK, 2011; UNEP, 2011). Concurrently, the concept of climate change localisation and management has also been gaining centre stage (Wright et al., 2011). These calls are based on a range of logics. Economically, air quality co-benefits of green house gases (GHG) reduction policies could potentially offset a large fraction of the cost of the mitigation actions, particularly in developing countries (Stern et al., 2007; Nemet et al., 2010). Technically, actions to reduce certain air pollutants (so called 'Short Lived Climate Forcers') may be particularly advantageous in slowing the rate of warming (Ravishankara et al., 2012), particularly in the situation where significant GHG reduction may be a long-time coming.

Integrated air quality management and GHG reduction measures have been reported to offer greater benefits than those obtained from implementation of isolated measures (Chae and Park, 2011). Hence, greater emphasis is being laid on 'holistic' LAQM plans and strategies, incorporating climate change considerations, or vice versa, e.g. London Borough of Brent (2012). However, despite the high-level calls for joined up action on air quality and climate change, the notion of 'co-management' has received little in-depth exploration at local scales. The key question remains whether significant carbon management might be better achieved utilising the same framework as applied by the LAs in the context of air quality. Although, theoretically LAQM can be used to support climate change mitigation in the short-to-medium term (Thambiran and Diab, 2011; Defra, 2011), the limited skill-base in LAs (developed and developing countries alike) in delivering this novel, cross-cutting agenda, augmented by the complexities in integrating local and scientific knowledge (Raymond et al., 2010), is likely to impede the expected outcome from improved integration of these two issues.

This paper sets out to highlight potential benefits and inherent barriers of localised co-management initiatives. It considers a number of opportunities for linking of these two policy spheres – combining the management of GHG and air quality. The first part presents an overview of the current practice and issues in LAQM and carbon management approaches. This is followed by three case studies, which present the challenges of consolidated actions and the possibilities and opportunities for converging the carbon and air quality agendas at a strategic level rather than just in terms of individual interventions. Based on these case studies the implications for an integrated adaptation strategy to co-management of urban environment and the pertinent hurdles to be overcome are discussed.

2. Current issues in local scale air quality and carbon management

Over the last decade LAs in the UK have been involved in rigorous assessments and declaration of Air Quality Management Areas (AQMAs) under the Local Air Quality Management (LAQM) policy framework. To date over 230 of the LAs (around 60%) have declared one or more AQMAs for different pollutants (predominantly NO_2 and PM_{10}). The sources of these pollutants are most commonly found to be transportation (over 95%), with a small minority due to industrial or domestic sources; the same sources that are primarily responsible for CO_2 emissions in the UK. This has already garnered attention from academics and policy-makers with regard to their co-management potentials. While there may be overlapping management needs in terms of addressing the reduction in emissions at source, typically from transportation, the inherent nature of how the two entities influence the local and the wider environment would significantly affect the potentials for co-management. Despite anthropogenic combustion activities being the prime sources of both GHGs and air pollutants in urban settings, there is a key contextual distinction between the methodological approaches for their effective management. Air quality has a strong spatial association with residential population (expressed as exceedences of the objectives) and requires a management-at-source approach to avoid adverse impacts. On the other hand, GHG reduction is not reliant on location-based interventions to achieve its targets (e.g. action to reduce carbon emissions in LAs are often focussed on energy saving initiatives in relation to power plant CO_2 emissions that occur well outside their boundary). However, this tendency may be about to change if the new $PM_{2.5}$ exposure reduction responsibilities (European Parliament, 2008) get passed down to LAs in any way, as this will result in LAs needing to make reductions in overall, background, pollution concentrations rather than just focussing on hotspots.

The links between air quality and carbon management lie not only in overlaps between the sources of interest, but also in the skills and policy understandings needed for their effective management (Baldwin et al., 2009). Devising the best approach to achieve ‘win-wins’ (i.e. likely to result in the reduction of pollutants of importance to air quality and climate change) from such co-management initiatives is an evolving phenomenon (Baldwin et al., 2009). Currently (2012) the policy of managing climate change through local environmental initiatives is gaining ground and increasing amounts of mitigation and adaptation methods for climate change are being implemented at local scales (AQMRC, 2010). However, to facilitate this, policymakers require an understanding of the air quality ramifications of climate mitigation decisions (or at least clearly presented and plausible evidence). Whilst win-win policies are obviously most desirable, it is envisaged some actions will result in a 'trade-off', benefitting one aspect at the cost of the other. Over recent years some expertise involved in air quality management has been diverted in finding a common path for providing guidance and support to LAs on the issues and problems associated with this approach. The main area for combining carbon management with LAQM is around transport emissions. This is due to the legacy of effective air pollution control after the 1965 Clean Air Act in the UK, which has meant that in the urban areas there is very little in the way of industrial or domestic emissions, and the vast majority of LAQM practice (at the moment) is based on transport, though this may be changing due to the recent ‘dash to biomass’ with regard to ‘sustainable’ heating systems for buildings (see Case Study III below).

Robust policies to co-manage climate and air quality have the potential to create significant reductions in exposure to air pollution (Ravishankara et al., 2012). Through the case studies in the following section, numerous opportunities, barriers and compromises are identified in order to effectively and resourcefully co-manage and mitigate CO_2 and LAQM pollutants while ultimately accruing cost-effective environmental benefits at LA levels.

3. Case studies

The following three case studies present practical and policy interactions in co-managing climate change and air quality through local initiatives, creating opportunities for positive gains for both issues (i.e co-benefits) as well as the inherent challenges in assessing what is beneficial for one could be deleterious for the other (i.e. trade-offs).

3.1. Case Study I – Reading Borough Council Air Quality and Climate Change Consultation (Integrated policies)

In 2007/8 Reading Borough Council (RBC), UK conducted a public and stakeholder consultation exercise to support the coordinated development of its Air Quality Action Plan and a Climate Change Strategy for the Borough (RBC, 2008). The two-phase consultation was designed to look at the interlinked issues of climate change and air quality so that areas with potential synergies and conflicts could be identified and adequately addressed (RBC, 2009 [p20]). The first phase consisted of awareness raising activities - including outreach events in the local libraries, community centres, leisure centres and community group talks. The second phase was conducted in partnership with the Air Quality Management Research Centre (AQMRC) at the University of West England, UK. This consisted of a questionnaire survey and two participatory workshops. The questionnaire surveys were distributed in various ways including a stand in a local supermarket, a double page spread in the local newspaper, through libraries and leisure centres and by post to people who had requested further contact through the postcard consultation. In total 155 questionnaires were returned and 24 people attended the workshops. Overall, local interest in environmental issues were found to be somewhat split, with local councillors more interested in engaging in a problem of global importance such as climate change, whilst citizens wanting to see more action from the local authority on the problems that are immediately at their doorstep. In response to query on the most important environmental issue 53 people identified road traffic, 39 air quality and 16 the need to mitigate climate change (Chatterton et al., 2008). A co-management approach offered an opportunity for the LA to develop strategies and policies that meet the expectations of both their elected members and their citizens.

Following this consultation, RBC have developed a Climate Change Strategy Action Plan, joining the two separate policy streams of air quality and climate change, specifically regarding policies on emissions sources (e.g. transport and decentralised energy) (RBC, 2008). It includes 40 sets of cross-thematic objectives and actions with their estimated benefits in monetary terms. **Table 1** provides a shortlist of those objectives that cover potentials for co-management within the scope of this paper. In addition, in the council's Air Quality Action Plan, 14 out of the 26 proposed measures have potential climate change benefits associated with them. This means that when it comes to assessing the cost-effectiveness of these measures (as required by government guidance LAQM.PG(09)) the council would be able to recognise and evaluate these additional (non-AQ) benefits. By visibly and publically making a link between the two issues, the council has helped ensure that political weight (stemming from either a desire to improve air quality or to mitigate climate change) can be put behind win-win measures through integrated policies, further increasing the likelihood of their implementation.

<place Table 1 here>

Currently (2012) there is no prescriptive legislative requirement for LAs to act on climate change mitigation; there has been a tendency for strategies to be developed at a higher, corporate level (or at least in part of the structure with a more cross-cutting remit than environmental health). The joint consultation process has helped to firmly link the issues in the eyes of the local managers, ensuring that whilst there are still separate Climate Change Strategy and Air Quality Action Plans, these now clearly pay reference to each other and have policies which fall across both, facilitating an overarching level of co-management.

3.2. Case Study II – All London Green Grid (Win-wins)

There is an emerging trend in inclusion of green infrastructure (GI) in the design, planning and management of landscape resources to conserve ecosystem functions and provide a range of co-benefits to the people. In the UK all LAs are required to have a Planning Policy Guidance (PPG17) open space strategy and accompanying dataset, though GI planning is still feeble in most cases, primarily owing to their difficulty in devising successful strategies (Defra, 2012). For example, even though all the London Boroughs work within the same policy context and guidance (ODPM, 2001), there is no standard protocol for classification and mapping of individual spaces. The East London Green Grid (ELGG), promoted by the Greater London Authority (GLA) as a network of multi-purpose open spaces criss-crossing the Thames basin, has accrued (or anticipated) benefits (including carbon reduction) to the tune of £4.93 to every £1 of London Development Agency investment (LDA, 2011). This initiative has now been extended across London in the form of All London Green Grid (ALGG), which aims to secure a network of high quality, well designed and multifunctional green and open spaces (**Figure 1**). It has earmarked co-management opportunities in terms of ‘ALGG functions’, including adaptation to climate change; improvement of air quality and soundscapes; conservation and enhancement of biodiversity; promotion of healthy living; improve quality and access to urban fringes. (GLA, 2012).

<place Fig 1 here>

This case study presents the potential benefits and limitations to co-management opportunities from local scale GI planning and design strategies. It covers a section of the ALGG in the Lower Lea Valley, around the area of the City Airport and its flight paths across East London (shown with a dotted square in **Figure 1**). The estimates of CO_2 and PM_{10} in the assessment have been generated using activity and emissions data from the London Atmospheric Emissions Inventory (LAEI) (GLA, 2010), primarily from transportation and domestic sources (**Figure 2**). The spatial configuration of the green grid network and the flight path of the City Airport are shown in greater details in the inset of this figure, with the airport runway depicted as solid black rectangle. Adequate design and vegetation composition would offer co-management potentials for CO_2 emissions as well as wind and air quality amelioration (mainly particulate pollution) across the region, but has inherent land use challenges - for example restrictions to planting tall trees very close to the runway. From air quality perspective mixed tree cover, comprising of 75% grassland, 20% sycamore maple (Acer pseudoplatanus L.) and 5% Douglas fir (Pseudotsugamenziesii) has been shown to achieve PM_{10} reductions in London of up to 0.17 tonne ha^{-1} yr^{-1}(Tiwary et al., 2009). For CO_2 management on the other hand, there are different priorities in species selection; establishments of new woodlands have been shown to contribute to much higher yearly potential carbon sequestration (up to 3.63 tonne C ha^{-1} yr^{-1}), compared to bioenergy crops, short rotation coppice (SRC) and Miscanthus cultivation (up to 0.41 tonne C ha^{-1} yr^{-1}) (Cantarello et al., 2011).

<place Fig 2 here>

Emissions of CO_2 and PM_{10} at 1 sq-km resolution for 2011, based on the LAEI are plotted along with the design of the ALGG network in the study domain (**Figures 3a and 4a respectively**). Potential co-benefits have been estimated on the basis of reported carbon sequestration (Cantarello et al., 2011) and PM_{10} fluxes (Tiwary et al., 2009) applied to a mixed plantation, comprising of 75% grassland, 20% sycamore maple (Acer pseudoplatanus L.) and 5% Douglas fir (Pseudotsugamenziesii) for the 10,000 ha plot.

<place Fig 3 here>

The potentials for CO_2 sequestration is estimated in terms of annual flux to the vegetation (tonnes km^{-2} yr^{-1}, **Figure 3b**) whereas the air quality co-benefit is estimated as reduction in PM_{10} concentration downwind to the plantation (at 1.5 m height about ground) (µg m^{-3}, **Figure 4b**). The outputs support co-management potentials of the ALGG near the City Airport for both CO_2 and PM_{10} reductions through efficient design and choice of species, facilitating both enhanced dry deposition of pollutants on their foliage and localised carbon sinks for aircraft emissions in the region.

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While the pedagogical evidence generated through this case study is promising towards supporting multi-functional urban greening policies, it is still limited in scope in overcoming the inherent challenges in realising these functions, utilising the skills available in LAs. This would be essentially at two stages of greening projects: i) appropriate design and implementation; ii) adequate appraisal of their co-management potentials.

3.3 Case Study III – Decentralised Energy from Renewable Biofuels (Trade-offs)

Development of a reliable and clean energy infrastructure has been at the forefront of local planning framework in recent years, with potential co-benefits to improvement of public health and for climate change mitigation (Haines et al., 2007). Biomass from both organised plantations (including energy crops) and solid wastes has been considered an integral component of the green energy mix in the UK towards development of smaller, decentralised heat and electricity applications in a multiplicity of locations (Barker and Evans, 2009; Bauen et al., 2010). However, co-management opportunities from these initiatives have not proven to be effective at a systems level, and there is a significant risk identified for deleterious impacts on air quality at the expense of lower carbon energy and heat generation (Gallagher et al., 2008). In the UK new sets of guidance have been developed exclusively for LAs to address adverse air quality issues from biomass boilers and Combined Heat and Power (CHP) installations. These provide recommendations and spreadsheet-based screening tools to local managers for assessing and managing the potential air quality impacts, specifically for nitrogen dioxide (NO_2) and particulates (PM_{10} and $PM_{2.5}$) (EPUK, 2009; 2012). It is acknowledged that the potential risk of a breach of air quality standards is increased if the CHP system is in or near an AQMA, attributed to the compounded impacts from associated activities at urban and regional scales. However, in the absence of any clear guidance, LAs are left to decide on the level of impact the installation would have directly within their bounds.

<place Fig 5 here>

This case study develops a hypothetical scenario for a decentralised bioenergy system spanning across two neighbouring LAs (LA1 and LA2 in **Figure 5a**; to illustrate the need for overlapping responsibilities) and evaluates the CO_2 and air quality issues for utilising a range of renewable fuels scenarios from the literature. This is pertinent to local planning in the near future with a growing number of microgeneration schemes and smaller scale community boilers operating in peri-urban locations as part of GHG reduction strategy, with environmental responsibilities shared across the LA boundaries. However, LAs would not have direct responsibilities over imposing emissions control for the whole bioenergy system (for example, harvesting and non-road transportation and processing of biofuel would not be accounted within the LAQM framework). **Figure 5(b)** shows a spectrum of air quality burdens arising from different biofuel CHP systems from the harvest, transport and power plant (here A=Miscanthus; B= Short rotation coppiced (SRC) wood; C=Residual waste wood; D=80% Miscanthus + 20% Residual waste wood; E=80% SRC + 20% Residual waste wood) estimated from emissions reported in the literature (Tiwary and Colls, 2010). As can be noted, all the CHP systems studies have lower CO_2 burdens from the power plant (and hence promoted as green technologies), albeit at the cost of enhanced NO_x, N_2O, SO_2 and HCl emissions. This would potentially trigger interaction of criteria pollutants, exacerbating health risks from both primary and secondary pollutants, photochemical smog formation (ozone) and eutrophication (through nutrient enrichment) in the local environment, as well as impacting on the regional climate from secondary aerosol formation (Tiwary et al., 2012).

In policy terms this case study highlights the need for strengthening systems scale capabilities to assess and effectively mitigate the impacts of such complex and spatially distributed concomitant emissions, spanning across a range of activities involved in fuel harvesting, pre-processing and consumption. Evidently, such initiatives would ask for a more integrated co-management framework, with greater cross-territorial interactions between the LAs than currently pursued (i.e. beyond the basic LAQM approach).

4. Discussion

The above case studies offer pathways to how air quality and climate change can be (and arguably need to be) linked within LAs: to ensure the full benefit is obtained from complex win-win scenarios; to avoid, or at least minimise, the risk and extent of trade-offs where climate related policies might impact negatively on air quality; to ensure that co-ordinated agendas are taken forward at strategic levels in order to buy-in support from as many councillors and members of the public as possible; to be certain that positive impacts across the domains are fully accounted for in cost-effectiveness calculations for proposed measures. In the short-to-medium term the priority in co-management practices would be to implement air quality interventions that do not impact negatively on GHG emissions (Thambiran and Diab, 2011) and vice-versa. However, as clearly recognised in RBC's Air Quality Action Plan (**Table 1**), the sources can differ considerably between the two management spheres, leading to a need to keep the two separate to some degree. On the other hand, the overlap between sources and the interplay between the impacts of both technical and behavioural remedies for each highlights the opportunity for significant synergies that can be achieved.

Although, at least in principle, co-management initiatives are expected to be able to attain co-benefits in terms of both climate change mitigation and air pollution abatement (Baldwin et al., 2009), the majority of existing air quality related legislation has a limited ability to enforce interventions with such cross-cutting implications and bring about effective improvements. Some commonalities in the required skill base between air quality and carbon management for LAs have been identified, including a. existing networks of contacts; b. understanding of gaseous (and other) emissions; c. construction of emissions inventories; d. understanding of role, behaviour and regulation of a range of sources; e. identification of priority polluters. However, current LAQM being predominantly considered a health-based framework are focussed mainly on the exceedences in areas where receptors are likely to be exposed to the offending pollutant(s). This provides scope for the sources of emissions to be isolated and separated from the receptor without the need to reduce overall emissions. Conversely, carbon mitigation is concerned with reduction in the total load of emissions. Further, whilst the focus of LAQM is on emissions from sources, much of the work at a local level in terms of carbon management is in relation to end-use energy demand. For example, in the UK approximately 40% of CO_2 emissions within the scope of influence of LAs arise from electricity usage, rather than direct emissions (DECC, 2011). This means that a significant amount of the focus of any local carbon management activities would, in any case, fall completely outside the remit of LAQM.

Whilst technological and policy-based strategies have been shown to be effective in simultaneously reducing air pollution and GHG emissions from the transportation sector (Thambiran and Diab, 2011) there is considerable evidence of LAQM and climate change initiatives still working in silos (Chatterton et al. 2007; Longhurst et al. 2009; IHPC, 2010; Olowoporoku et al. 2012). On the other hand, owing to the inherent distinction between the manner in which the two sources affect the human and the natural environments this does not necessarily imply that carbon management can be best achieved at a local scale by following similar policy frameworks and guidance to those currently used for air quality.

5. Synthesis and Future works

To date LAs in the UK have been set targets for air quality but they have not yet (i.e. in 2012) been set specific carbon reduction targets as such. Current initiatives, being pursued under the broader 'sustainability' umbrella at LA level, have climate mitigation agenda per se with either co-benefits or adverse impacts to air quality. A well-defined co-management framework, integrating carbon and air quality management on a single platform, is long overdue. Ideally this needs to facilitate the practitioners in a two-stage process - first, to develop a common metrics for the LAs, assisting them in ascertaining whether co-management would be more effective compared to working on air quality or carbon management in isolation in their respective areas; second, to prescribe them a customised local/regional implementation plan, linking with the broader strategic objectives at national level. In essence this would ascertain the impact of co-managing initiatives, albeit inadvertently or by design, which can manifest into either win-win (e.g. ensuring both lower emissions and freer flowing transportation) or win-lose/trade-offs (e.g. traffic calming measures adapted for reduced congestion but increased travel distance circumventing the city routes).

Whilst a 'co-benefits' approach (to a wide-range of other environmental and social factors) has always been a feature of local planning framework in the UK, there is a spectrum of potential for 'co-management' in the rapidly urbanising economies world-wide, which runs simply from the assessment of co-benefits, through to complete alignment of policy and management techniques. This paper, however, highlights that in the short–term atleast, the delivery of this novel, cross-cutting agenda may be impeded owing to limited expertise of local managers (developed and developing world alike) in assessing the synergies and the expected outcome from improved integration of these two issues. It is expected that a step-change through a more integrated, trans-boundary policy framework, going beyond the local administrative spheres, would maximise the co-management potentials while mitigating the wider environment impacts. Whilst a full integration of air quality and climate change responsibilities in LAs may not (in all cases) be desirable, there is a strong need for a significant degree of integration to be recommended through adequate policy framework and best practice. Without this to direct the LAs, there is a huge risk that opportunities to co-management will be overlooked, ignored, or simply not receive the necessary local political priority.

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Abhishek Tiwary is a senior researcher in the School of Civil Engineering and Geosciences at Newcastle University, UK. His expertise is in cross-sectoral evaluation of infrastructure sustainability, in terms of Energy and Emissions from environmental change adaptation strategies, maximising co-benefits to the population and the environment. He has been involved in several studies on systems-scale assessment of built-natural environment interactions.

Tim Chatterton is a senior research fellow in the Air Quality Management Resources Centre, University of West of England, UK. His work deals with the wider sustainability agenda at the interface of research and policy covering the social and physical sciences. His expertise include co-management of carbon and other pollutant emissions from transport and building, covering a wide range of research and training activities across the UK, Africa and Asia.

Anil Namdeo is a senior lecturer in Transport and Sustainability in the School of Civil Engineering and Geosciences at Newcastle University, UK. His expertise is in environmental assessment of land use and transport policies, linking air quality, social deprivation and health.

Tables and Figures Captions

Table 1. Policies addressing co-management issues in the Reading Borough Council Climate Change Action Plan (source: RBC, 2008)

Figure 1. Spatial mapping of the proposed All London Green Grid and the case study area, Lower Lea Valley green space (shown in dotted square).[© Crown Copyright and database right 2011. Ordnance Survey 100032216] (source: GLA, 2012).

Figure 2. The model domain showing the road and rail traffic (lines), 1 sq-km emission grids, London City airport (rectangle), flight paths (trajectories) and the square box showing the configuration of the green grid. Further details of the spatial layout relative to the street plan and the airport runway locations are provided in the inset. [© Crown Copyright and database right 2011].

Figure 3 (a) CO_2 hotspot map for London for 2011. (b) Estimated annual CO_2 flux potentials for the case study site (at 1 sq-km grid resolution).

Figure 4 (a) PM_{10} hotspot map for London for 2011. (b) Contour map of PM_{10} reduction potentials for the case study site (as concentration reduced downwind to the vegetation at 1.5 m height above ground level).

Figure 5 (a) Schematic of the conceptualised management boundary of a decentralised bio energy system shared between two local authorities [note: all the activities except biomass production would be accounted within the LAQM; the concomitant interactions of criteria pollution requires a more regional management framework; T = Transport]. (b) Bar plot of emissions from biofuel-based CHP at systems scale, including biofuel harvest/sourcing, transport, processing/drying and combustion [A=Miscanthus; B= Short rotation coppiced wood; C=Residual waste wood; D=80% Miscanthus + 20% Waste wood; E= 80% SRC + 20% Waste wood].

Figures

Fig 1

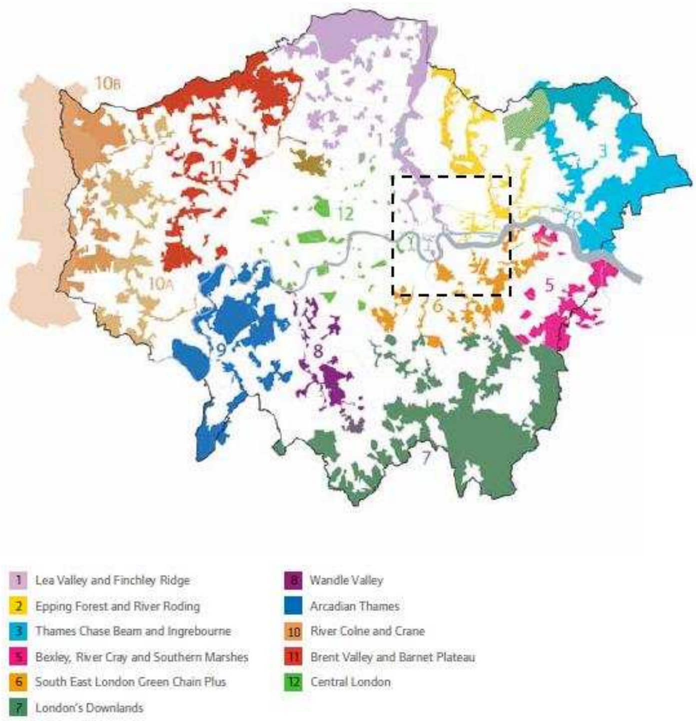


Fig 2.

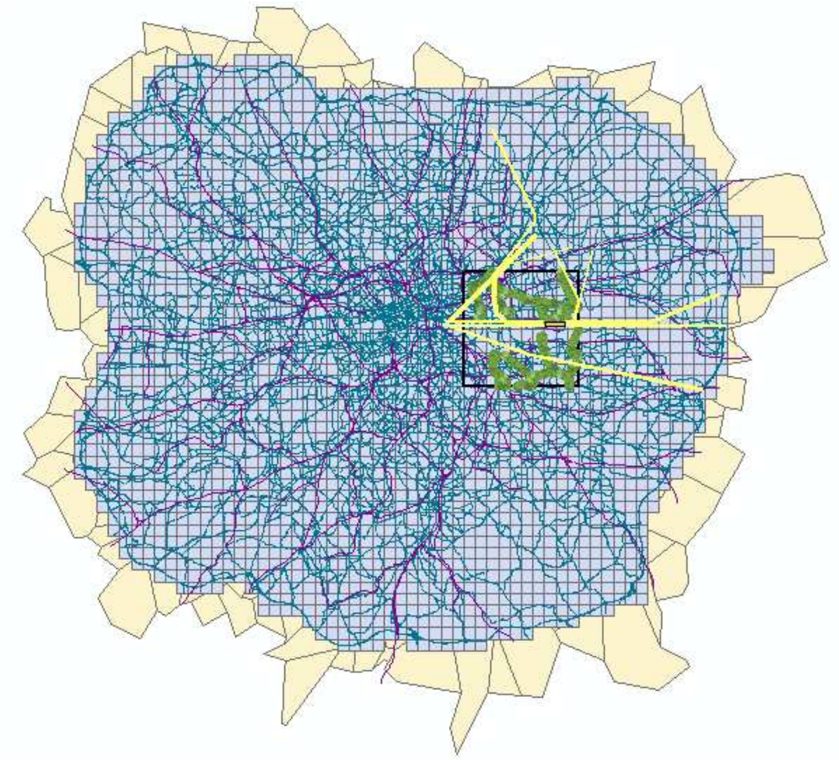


Fig 2 (inset)

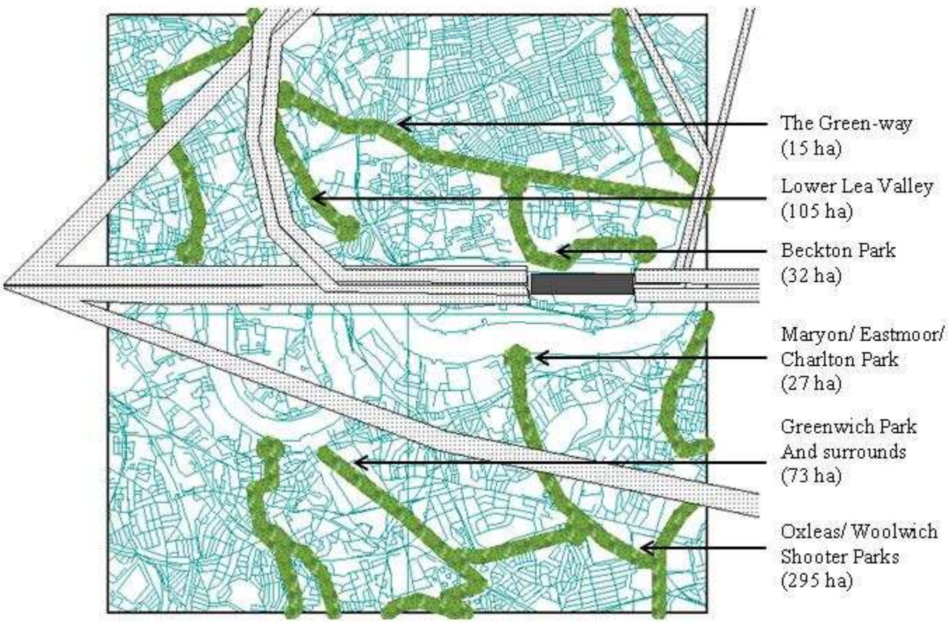


Fig 3(a)

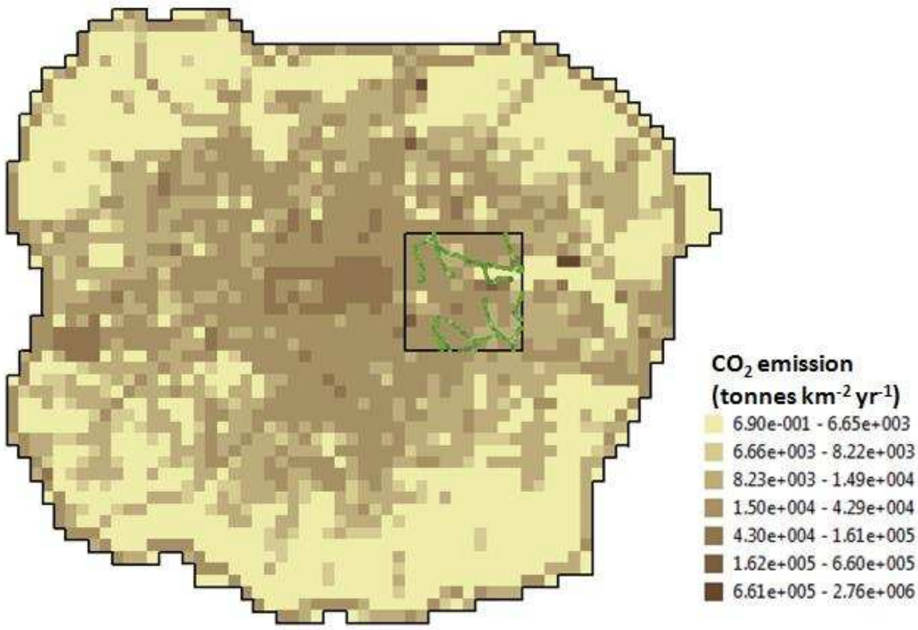

CO_2 emission
(tonnes km^{-2} yr^{-1})
6.90e-001 - 6.65e+003
6.66e+003 - 8.22e+003
8.23e+003 - 1.49e+004
1.50e+004 - 4.29e+004
4.30e+004 - 1.61e+005
1.62e+005 - 6.60e+005
6.61e+005 - 2.76e+006

Fig 3(b)

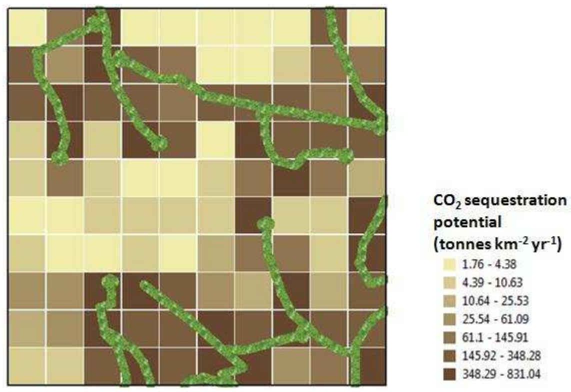

CO_2 sequestration
potential
(tonnes km^{-2} yr^{-1})
1.76 - 4.38
4.39 - 10.63
10.64 - 25.53
25.54 - 61.09
61.1 - 145.91
145.92 - 348.28
348.29 - 831.04

Fig 4(a)

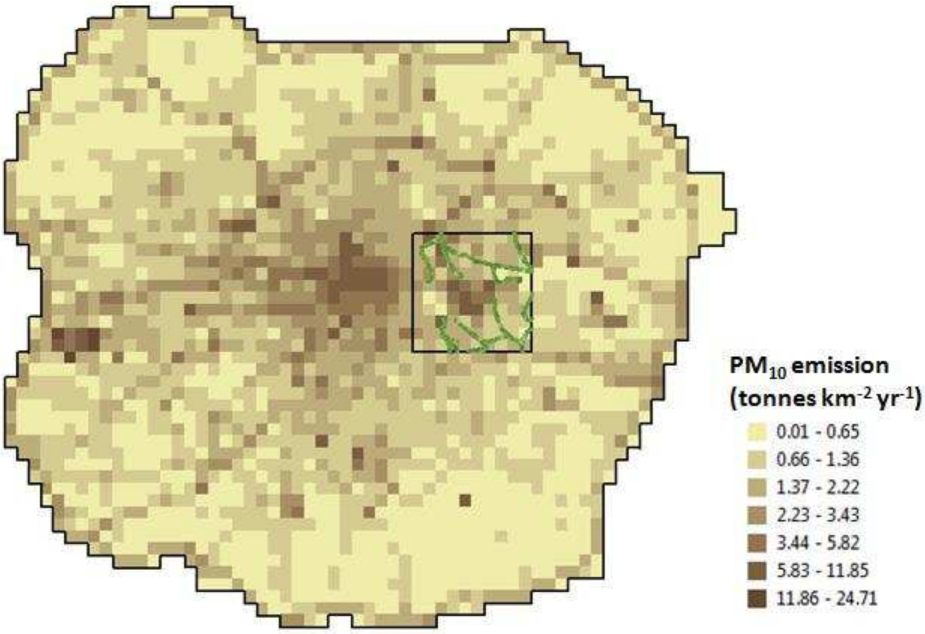

PM10 emission
(tonnes km-2 yr-1)
0.01 - 0.65
0.66 - 1.36
1.37 - 2.22
2.23 - 3.43
3.44 - 5.82
5.83 - 11.85
11.86 - 24.71

Fig 4(b)

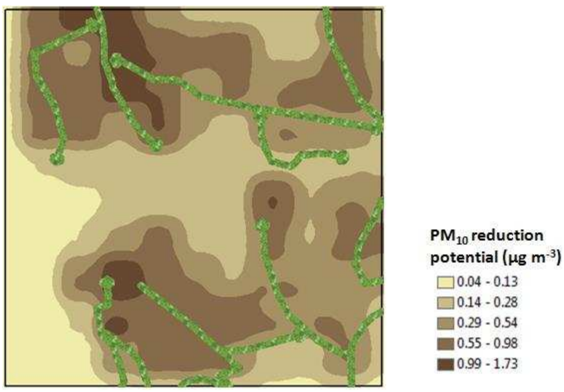

PM10 reduction
potential (μg m-3)
0.04 - 0.13
0.14 - 0.28
0.29 - 0.54
0.55 - 0.98
0.99 - 1.73

Fig 5(a)

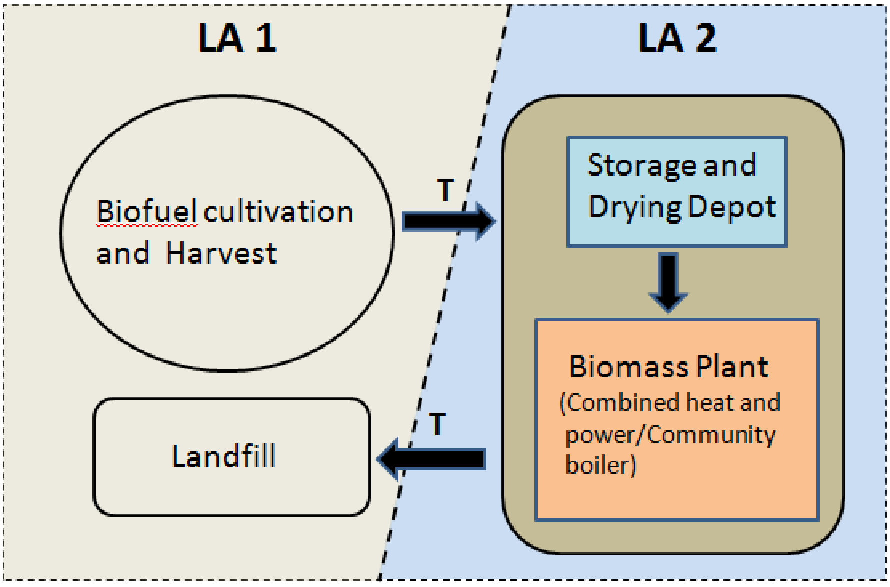
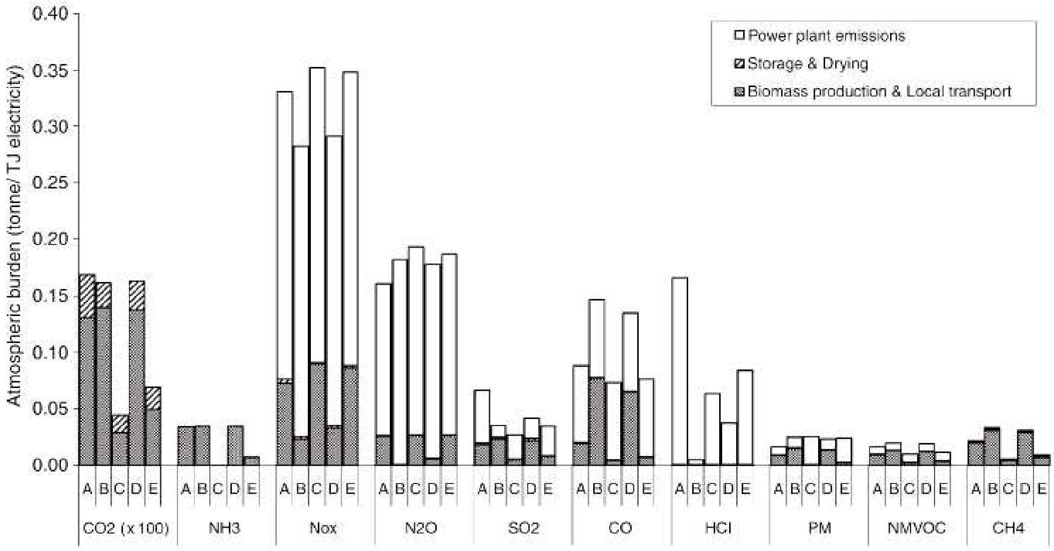

LA 1
LA 2
Biofuel cultivation and Harvest
T
Storage and Drying Depot
Biomass Plant
(Combined heat and power/Community boiler)
T
Landfill

Fig 5(b)


Atmospheric burden (tonne/ TJ electricity)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Power plant emissions
Storage & Drying
Biomass production & Local transport
A B C D E
CO2 (x 100)
NH3
Nox
N2O
SO2
CO
HCl
PM
NMVOC
CH4